CANADIAN PURCELL MACHINERY LTD.

"A World of Compressed Air & Gas Solutions"

TECHNICAL BULLETIN

UNDERSTANDING COMPRESSOR CAPACITY

INTRODUCTION

One of the most perplexing issues facing the compressor purchaser is an understanding of the term CFM, which is widely used to define the capacity of a compressor.

This problem is complicated by the wide array of terminology used to express compressor capacity. Since this term is also expressed as SCFM, ACFM and ICFM. So what are the differences?

Without a clear understanding of this terminology the client runs the risk of purchasing a compressor that doesn't deliver an adequate volume of air, or one that is far oversized, resulting in wasted energy costs.

Further confusion is caused by the fact that manufacturers and users of compressed air equipment discuss the capacity in terms of "compressed air", when in reality they are generally discussing free or expanded air, which has been compressed.

To clearly discuss air compressor capacity we must first understand a three important points.

1. Air has weight and mass!

   The density of air is directly proportional to the atmospheric pressure. Therefore the capacity of an air compressor operating in Denver Colorado (elevation 5200 ft/12.2 PSIA) will be less than an air compressor operating in Vancouver, B.C. (sea level/14.7 PSIA).

2. The humidity of the air will, to some extent, affect the capacity of an air compressor!

3. A high temperature reduces the weight (mass) flow of each cubic foot of air. Therefore the same compressor will deliver a lower volume of air on a hot day, than it would on a cold day.

Following are several terms, which are widely used in the industry. Having an understanding of each will clear up some of the confusion that surrounds any discussion into compressor capacity.

CFM

Simply put, CFM is an acronym for Cubic Feet Per Minute. Cubic feet per minute (CFM) is however, an unqualified term and should only be used in general and never be accepted as a specific definition.

DISPLACEMENT CFM

This term applies only to positive displacement type compressors and is the volume displaced per unit of time, generally expressed in cubic feet per minute (CFM). In a piston compressor it is the swept volume of the piston as it moves through the cylinder, or the net area of the piston multiplied by the length of the stroke, times the number of strokes per minute.

This piston displacement of a multi-stage compressor is the total displacement of the low pressure or first stage cylinders only.

For double acting compressors it is the swept volume of the low-pressure piston on BOTH the upward and downward strokes.

This figure does not take into account inefficiencies caused by the air cleaner, inlet piping restrictions, as well as leakage past the inlet valves and piston rings. It is in no way representative of the volume of air that will actually be delivered by the compressor.

Piston displacement should therefore <u>never</u> be used when evaluating an air compressor's performance!

FREE AIR

Free air, as defined by CAGI (Compressed Air & Gas Institute) is air at ATMOSPHERIC conditions at any specific location. Because the barometer and temperature may vary at different localities and at different times, it follows that this term does not mean air under standard conditions. Before any calculations can be made to convert FREE AIR into flow at other conditions, the barometric pressure, temperature and relative humidity at the site must be established.

FREE AIR DELIVERY (FAD)

Measured in CFM (Cubic feet per minute) this is the amount of compressed air converted back to the actual inlet (free air) conditions before it was compressed. In other words, the volume of air, which is drawn in from the atmosphere by the compressor, then compressed and delivered at a specific pressure.

SCFM (STANDARD CUBIC FEET PER MINUTE)

SCFM (Standard Cubic Feet per Minute) is the volumetric flow rate of a compressor corrected to specific "standardized" conditions of temperature, pressure and relative humidity. This therefore, represents a precise mass flow rate. However, care must be taken, as "standard" conditions vary between North America and Europe and industry to industry. Here in North America "standard" conditions for pressure are 14.696 (14.7) PSIA and the "standard" temperature is generally defined as 60^{o} F. The relative humidity is also included in some definitions of standard conditions and here in North America the standard is 36% RH.

Because the actual conditions are clearly defined, SCFM offers the best method of stating capacity.

ACFM (ACTUAL CUBIC FEET PER MINUTE)

Is the air flow in cubic feet per minute measured at the actual pressure and temperature that exists at the specified reference point? The specified reference point can be defined anywhere in the system.

SCFM (STANDARD CFM) VS ACFM (ACTUAL CFM)

In specifying compressor performance, significant problems often occur in distinguishing ACFM from SCFM and in correctly converting from one to the other. People frequently and improperly interchange the use of ACFM and SCFM.

As actual site conditions are different from the standard or reference conditions, corrections must be made to reflect the actual conditions of pressure, temperature and relative humidity (i.e. convert to ACFM).

These corrections must, therefore, be made to assure that the compressor furnished will provide the proper volume of air.

To convert SCFM to actual flow (ACFM) at any other pressure and temperature conditions, the basic formula used is:

$$ACFM = SCFM \ X \ \frac{Ps - (RH_s \ X \ PV_s)}{P_b - (RH_a \ X \ PV_a)} \ X \ \frac{T_a}{T_s} \ X \ \frac{P_b}{P_a}$$

Where:

P_s = Standard Pressure (PSIA): Generally 14.7 PSIA
P_b = Atmospheric pressure (PSIA) at site: See attached elevation chart
P_a = Actual compressor inlet pressure (PSIA): Atmospheric pressure – inlet pressure drop
RH_s = Standard relative humidity: Generally 36%
RH_a = Actual relative humidity
PV_s = Saturated vapor pressure of water at standard temperature (PSI): See attached vapor pressure chart
PV_a = Saturated vapor pressure of water at actual temperature (PSI): See attached vapor pressure chart
T_s = Standard temperature (^oR) NOTE: ^oR = F + 460: Generally 60 + 460 = 520
T_a = Actual temperature (^oR) 1: ^oF + 520

Now lets put the equation to the test using the following criteria:

Site Elevation:	1,000 feet above sea level
SCFM:	1,000
Ambient Temperature:	80^o F
Relative Humidity:	70%
Inlet Pressure Drop:	0.3 PSI (due to compressor inlet filter and piping)
Standard Conditions:	14.7 PSIA, 36% RH and 60^o F

From the attached charts (Table 2) we can determine that the barometric pressure at 1000 feet of elevation will be 14.16 PSIA. From this we can calculate as follows:

$$ACFM = 1000 \ X \ \frac{14.7 - (0.36 \ X \ .2563)}{14.16 - (0.70 \ X \ 0.3632)} \ X \ \frac{(80 + 460)}{(60 + 460)} \ X \ \frac{14.16}{13.86}$$

$$= 1000 \ X \ \frac{14.6}{13.9} \ X \ \frac{540}{520} \ X \ \frac{14.18}{13.86}$$

$$= 1000 \ X \ 1.05 \ X \ 1.04 \ X \ 1.02$$

= Approximately 1062 ACFM

As you can see, if the flow was not corrected for actual conditions, the capacity would be incorrect by approximately 6%. This would be a greater miss if all parameters stayed the same, but we assume a 100^o F ambient temperature. Based on a 100^o F day, the flow would be 1157 ACFM.

ICFM (INLET CUBIC FEET PER MINUTE)

This is the unit of measure used by some major compressor manufacturers and is defined as the volume of air discharged at a specific pressure, but referred back to inlet conditions (ie: expanded air).

It does not however, use a defined or specific set of ambient conditions. (ie.: specific altitude, atmospheric pressure, relative humidity etc.)

NM^3/HR (NORMAL CUBIC METERS PER HOUR

Although similar to the American Standard SCFM, this is the term used throughout Europe as designated by ISO (International Standards Organization).

The standards used are 0^0 C (32^0 F), 1 Bar (14.7 PSIA), 0% relative humidity and a density of 1.118 Kg/M^3 (0.7416 lbs/ft^3)

$$Nm^3/hr = SCFM \times 1.607467 \text{ or } SCFM \div .62210$$

WEIGHT FLOW (LBS/HR OR LBS/MIN)

Because most compressed air is used to exert force on some sort of pneumatic device or equipment and fore = "mass X acceleration" the amount of force exerted will depend on the mass flow of the air, the conclusion one would therefore reach is that the only accurate way to evaluate a compressor capacity is to compare the weight flow of air under identical ambient conditions.

Once inlet conditions are known, it is a rather straightforward procedure to convert to ICFM, by the Perfect Gas Law:

$$V = \frac{ZWRT}{144(P)}$$

Where:
- V = Volume at inlet conditions (CFM)
- Z = Compressibility (equals 1.0 in most cases)
- W = Weight flow of gas (lbs./min.)
- R = Gas constant (53.3 for dry air only)
- T = Inlet (Ambient) temperature (^{0} R)
- P = Inlet (Atmospheric) pressure (PSIA)

Even with this quantity there are pitfalls. You must specify if the weight flow includes moisture present, or not (wet or dry).

It is worthwhile noting that SCFM defines a weight flow, since for SCFM the atmospheric pressure, inlet temperature, relative humidity and gas constant for air, are totally defined. Utilizing the above to obtain density from the CAGI standards one can calculate the 0.075 lbs/ft^3 previously mentioned.

MMSCFD

MMSCFD which stands for Million Standard Cubic Feet per Day of gas is predominantly used in the United States where MM means 1000 x 1000 (or one million). MMSCFD is a measure of natural gas, LPG (Liquefied Petroleum Gas), CNG (Compressed Natural Gas) and any other gases extracted, processed or transported.

MSCFD

Another term often used in the natural gas industry, particularly for smaller gas compressors, is MSCFD or Thousand Standard Cubic Feet per Day.

Careful attention must be paid as this term is often thought to stand for MILLION cubic feet rather than THOUSAND cubic feet.

TABLE 1

VAPOR PRESSURE VERSUS TEMPERATURE

Temp (°F)	Vapor Press (PSIA)	Temp (°F)	Vapor Press (PSIA)	Temp (°F)	Vapor Press (PSIA)	Temp (°F)	Vapor Press (PSIA)	Temp (°F)	Vapor Press (PSIA)	Temp (°F)	Vapor Press (PSIA)
32	.08859	48	.16520	64	.2952	80	.5073	96	.8416	112	1.3516
33	.09223	49	.17151	65	.3057	81	.5241	97	.8677	113	1.3909
34	.09601	50	.17803	66	.3165	82	.5414	98	.8945	114	1.4311
35	.09992	51	.18477	67	.3276	83	.5593	99	.9220	115	1.4723
36	.10397	52	.19173	68	.3391	84	.5776	100	.9503	116	1.5145
37	.10816	53	.19892	69	.3510	85	.5964	101	.9792	117	1.5578
38	.11250	54	.20635	70	.3632	86	.6158	102	1.0090	118	1.6021
39	.11700	55	.2140	71	.3758	87	.6357	103	1.0395	119	1.6475
40	.12166	56	.2219	72	.3887	88	.6562	104	1.0708	120	1.6940
41	.12648	57	.2301	73	.4021	89	.6772	105	1.1029	121	1.7417
42	.13146	58	.2386	74	.4158	90	.6988	106	1.1359	122	1.7904
43	.13662	59	.2473	75	.4300	91	.7211	107	1.1697	123	1.8404
44	.14196	60	.2563	76	.4446	92	.7439	108	1.2044	124	1.8915
45	.14748	61	.2655	77	.4596	93	.7674	109	1.2399	125	1.9438
46	.15319	62	.2751	78	.4750	94	.7914	110	1.2763	126	1.9974
47	.15909	63	.2850	79	.4909	95	.8162	111	1.3133		

TABLE 2

ELEVATION VERSUS ATMOSPHERIC PRESSURE

Elevation (ft)	PSIA	"HgA
0	14.7	29.92
100	14.64	29.81
200	14.59	29.7
300	14.53	29.6
400	14.48	29.49
500	14.42	29.38
600	14.37	29.28
700	14.32	29.17
800	14.26	29.07
900	14.21	28.96
1000	14.16	28.86
1100	14.11	28.75
1200	14.06	28.65
1300	14.01	28.54
1400	13.96	28.44
1500	13.91	28.33
1600	13.86	28.23
1700	13.81	28.13
1800	13.76	28.02
1900	13.71	27.92
2000	13.66	27.82
2100	13.61	27.72
2200	13.56	27.62
2300	13.51	27.51
2400	13.46	27.41
2500	13.41	27.31
2600	13.36	27.21
2700	13.31	27.11
2800	13.26	27.01
2900	13.21	26.91
3000	13.16	26.81
3100	13.11	26.71
3200	13.06	26.61

Elevation (ft)	PSIA	"HgA
3300	13.02	26.52
3400	12.97	26.42
3500	12.92	26.32
3600	12.87	26.22
3700	12.82	26.13
3800	12.78	26.03
3900	12.73	25.94
4000	12.68	25.84
4100	12.63	25.74
4200	12.59	25.65
4300	12.54	25.55
4400	12.5	25.46
4500	12.45	25.36
4600	12.4	25.27
4700	12.36	25.17
4800	12.31	25.08
4900	12.27	24.98
5000	12.22	24.89
5100	12.17	24.8
5200	12.13	24.71
5300	12.08	24.61
5400	12.04	24.52
5500	11.99	24.43
5600	11.95	24.34
5700	11.9	24.25
5800	11.86	24.16
5900	11.81	24.07
6000	11.77	23.98
7000	11.33	23.09
8000	10.91	22.22
9000	10.5	21.38
10000	10.1	20.58